# RADIOMETRIC EVALUATION OF DIGITAL AERIAL CAMERAS

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ABSTRACT:

Advanced radiometric properties of new digital photogrammetric sensors will open new applications for photogrammetric sensors. In order to learn to use the systems properly and to find out the limitations of the systems, sensor testing in operational conditions is essential. Radiometric properties of image data sets collected by Intergraph DMC, Leica ADS40, Vexcel UltraCamD and a medium format sensor Emerge DSS have been evaluated using the calibrated 8-step gray scale of the Finnish Geodetic Institute. In this article, exemplary results of various sensors are given. Results showed that saturation started at reflectance values of 27% to 66%, depending on the data sets. Central factors affecting the radiometric results were the sensor parameters during the image collection and the radiometric post-processing options. The presented results should not be used to compare various sensors but they are intended to demonstrate the many factors affecting the radiometric properties. However, results also show that in ideal conditions and with proper parameters the expectations set for the digital censors are fulfilled. Radiometric calibration and testing in field is crucial to utilize the advanced radiometric characteristics of the digital sensors to an optimum effect.

## 1. INTRODUCTION

A great advantage of the digital photogrammetric sensors over the analog ones is the superior radiometric quality. Important advantages include linearity, lower noise level (e.g. no granularity), better accuracy, better radiometric resolution and larger dynamic range. The improved radiometric quality will improve the usability of digital images both in visual and automatic interpretation tasks. (Sandau et al., 2000; Heier, 2001; Read and Graham, 2002; Perko et al. 2004; Leberl and Gruber, 2005; Markelin et al. 2005)

Several factors affect the radiometric properties of the airborne images. The sensor parameters (e.g. exposure, aperture) during the image collection must be set appropriately. Processing of raw data to the final images contains various phases affecting to the radiometry of images. Composition of one image from several CCD-sensors challenges the uniformity of the systems. Radiometric testing and calibration of the new digital photogrammetric sensors has been inadequately studied in the literature presented so far.

Radiometric testing and calibration of imaging systems requires accurate information about bidirectional reflectance distribution function (BRDF) of ground reference targets. These targets can be natural or artificial, permanent or transportable (Roujean et al. 2004). For comprehensive testing and calibration, the targets need to cover wide spectral range. Radiometrically stable natural targets may be hard to find and they do not always provide possibility for extensive calibration. The Finnish Geodetic Institute (FGI) is maintaining photogrammetric test fields in Finland and the most fundamental facility for radiometric evaluations is a transportable grey scale. It consists of eight reflectance targets (tarps) with nominal reflectance varying from 6% to 66%. They are designed to give flat spectrum and a near Lambertian reflection in the spectral range of 400 – 800 nm and in typical observing and illumination angles occurring during flights. The BRDFs of the FGI's targets have been measured accurately in laboratory and in field using the portable field goniospectrometer FiGIFiGo (FGI's Field Goniospectrometer) of FGI (Peltoniemi et al. 2005).

The objective of this study was to test radiometric properties of data sets from large-format photogrammetric cameras Intergraph DMC, Leica ADS40 and Vexcel UltraCamD and from medium-format sensor Emerge DSS. Our intention is not to compare various systems, because all the data sets were collected in different conditions. Instead, our intention was to find out the important parameters in the entire image production line.

## 2. MATERIALS AND METHODS

### 2.1 Imagery

All the major commercially available large format digital photogrammetric sensors have been tested in the Sjökulla test field of the Finnish Geodetic Institute (FGI) (Kuittinen et al. 1994, Ahokas et al. 2000, Honkavaara et al. 2006b) during recent years. The campaigns are described in detail in

| Camera | Date | GSD [cm] |
|---|---|---|
| UltraCamD + RC20 | 14.-15.10.2004 | 4, 8, 25, 50 |
| Emerge DSS | 12.7., 14.7.2005 | 6, 16, 50 |
| DMC + RC20 + goniometer | 1.-2.9.2005 | 5, 8, 25, 50 |
| ADS40 + RC20 + goniometer | 26.-27.9.2005 | 15, 25 |

Table 1. Image material

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Honkavaara et al. (2005, 2006a) and Markelin et al. (2005). Materials used in this study are presented in table 1.
The UltraCamD test-flights took place in late autumn 2004 (October 11th - 15th) mostly at noon. The sun angle was approximately 20˚ from horizon, thus the illumination conditions were ultimately poor. In this study data from test flights with 400 m and 800 m flying heights are used. For Hi-resolution images this results to GSD's 4 and 8 cm respectively. UltraCamD images were processed with OPC (Office Processing Center) v. 1.3.2. and final level_3 16bit images were measured.

The DMC test flights were performed in the beginning of September 2005 from 500 m, 800 m, 2500 m and 5000 m flying heights. In this study data from test flights with 500 and 800 m flying heights are used. For Hi-resolution images this results to GSD's 5 and 8 cm respectively. Data was collected in 1h 30min time during midday; the sun angle was approximately 35˚ from horizon. DMC images were processed with PPS (Post Processing Software) v. 4.4 and final 16bit-images were measured.

For UltraCamD and DMC images, the GSD always refers to GSD of Hi-resolution PAN-images. For the Lo-resolution multispectral images processed from the same raw-data, the true GSD's are approximately four times bigger than the PAN GSD's. Processing parameters were chosen to assure as original images as possible without any radiometric adjustments. High resolution (PAN sharpened) PAN, RGB and NIR and low resolution (no PAN sharpening) RGB and NIR UltracamD and DMC images were produced.

The DSS test flight was performed by Blom Geomatics at 12th and 14th of July 2005 from 200m, 1000m and 3000m flying heights, resulting GSD's of 6cm, 16cm and 50cm respectively. The aircraft was a Piper Navajo PA 31. DSS images were received from the company as final 8-bits per channel NIR images. Processing parameters were set for visual inspection, not especially for radiometric evaluations.

The ADS40 test-flights took place in autumn 2005 (September 25th - 27th) mostly at noon. The sun angle was approximately 35˚ from horizon. Estonian Land Board processed the ADS40 images. The flight campaign was one of the company's first tests with the camera. The sensor parameters during image collection were not optimised for radiometric evaluations. For example, the images were recorded in standard photogrammetric mode, which uses data compression and sacrifices some of the radiometric dynamics for storage size. Measurements were made from four multispectral and three panchromatic channels from raw-images. Staggering of PAN-arrays was not used.

RC20-images from UltraCamD-campaign were used as a reference material. Panchromatic film was scanned using 20um pixel size and 12bits and then converted to 8bit-images. Analogue reference imagery was collected simultaneously using RC20 of NLS (National Land Survey of Finland) during all campaigns except DSS.

Simultaneous BRDF measurements of reflectance targets were performed in field with the FiGIFiGo during the test flights of DMC and ADS40.

## 2.2 Grey scale

The FGI grey scale consists of eight reflectance targets of size 5 m x 5 m. Manufacturing and BRDF-properties of the grey scale are described in detail in Markelin et. al. (2006). All targets of grey scale were measured with FiGIFiGo at the laboratory under artificial light. Field measurements with the same equipment were done during DMC and ADS40-campaigns. Target reflectances were calculated separately for each colour channel according to spectral sensitivities of each sensor. In this study, only the nadir observation reflectance values are used. All target reflectances were slightly wavelength dependent; reflectance reduced from maximum to minimum in order blue, green, PAN, red and NIR, i.e. in order of growing wavelength (Figure xx).

The approximate laboratory nadir reflectances with illumination angle 56˚ from zenith are 6%, 10%, 17%, 23%, 27%, 42%, 46% and 63% (Figure 1). The field-data corresponded well with the laboratory measurements (Figure 1). Laboratory values are used in the following analysis.

In this study the target reflectance values were used. A exact method would be to transform the reflectances to the at sensor radiances by utilizing BRDF-information, atmospheric correction and individual imaging and illumination geometries of each image.

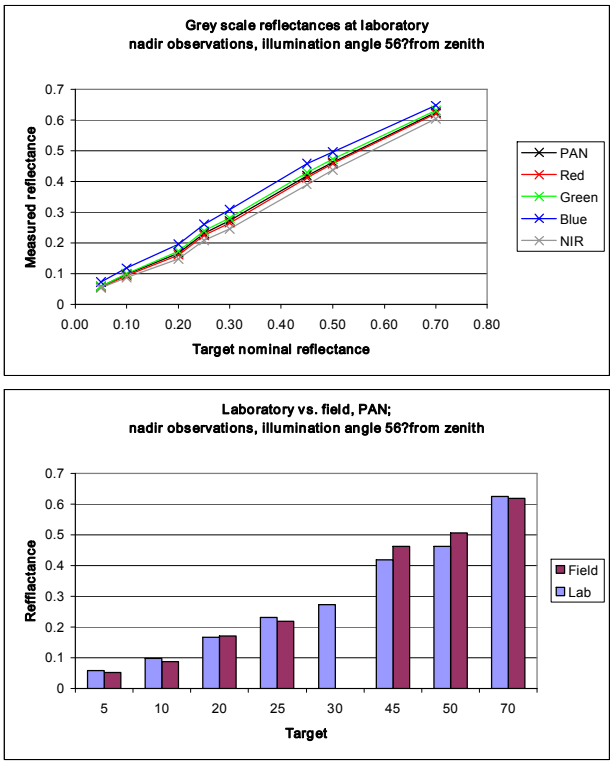


Figure 1. Top: Grey scale reflectance values measured at laboratory. Bottom: laboratory vs. field-measurements according to DMC PAN-wavelengh (target 30 was not measured in field).

## 2.3 Image measurements

The DNs of the reflectance targets of each colour channel were measured from all images. A vector layer containing 8 square

polygons of size 2 m x 2m on ground, one for each target, was created for every image. From these polygons the following statistics were calculated: mean, standard deviation, min, max. The mean values plotted against their true reflectances can be used to evaluate the linearity of the sensors.

Because the grey scale provides a flat even coloured target, standard deviation can be used to evaluate the amount of noise on the images. However, when assembled on field, reflectance targets of grey scale are not entirely flat, but there is noticeable topographic variation in targets resulting from rugged terrain under them (Figure 2). In the original target standard deviation obtained directly from the DNs, the major effect is this topography, which should be similar in the entire DN-range due to the linearity of the CCD-sensor. The standard deviation can be thus used to evaluate the radiometric resolution of the system.

The grey scale was average-filtered with different window sizes and extraction image of original and filtered image was evaluated in order to reduce the effect of the grey scale topography in standard deviation. The remaining standard deviation should be indicator of system noise. Baltsavias et al. (2001) has used slightly different method. To get results more comparable between different DN-ranges, the percentage of standard deviation from original mean DN-values was used as indication of noise. In the following, this percentage is called as a relative standard deviation.

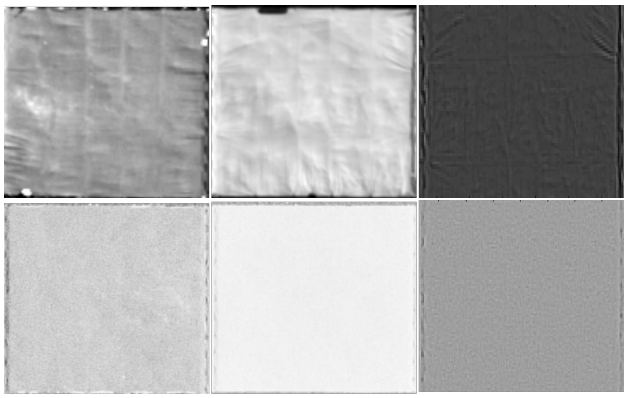

Figure 2. Top: Reflectance targets from DMC PAN image, bottom: Reflectance targets from RC20 film image. Left: 10% target, middle: 50% target, right: 50% target filtered with window of size 3x3. Images are radiometrically adjusted for visualization.

## 3. RESULTS AND DISCUSSION

### 3.1 Linearity and dynamic range

The average multispectral DNs plotted as the function of the reflectance are shown in figure 4. The first impression is that the linearity of digital sensors is good but that some color channels were saturated at the largest reflectance values (three brightest targets; reflectance 42% - 63%). Typically the most saturated channel was green and the most linear channel NIR. DSS results are not comparable to UltraCamD and DMC because of 8bits-per-channel images. RC20 results are typical for film-based images and images processed for visual use.

UltraCamD PAN and green channel were clearly saturated at the reflectance 46%. This may be result from poor illumination conditions and long exposure times. On unsaturated parts of the grey scale, the linearity of the sensor was good. There is a clear difference in the DN-values between the color channels; blue channel has the highest and NIR channel the lowest values on all targets, red and green are between them. The PAN-sharpening lowered the image DNs of all channels.

On DMC, the green channel saturated at the reflectance 46% and other multispectral channels at the brightest target of reflectance 63%. The PAN-channel was not saturated at all. The DN-values of red and blue channels were very close to each others, whereas green channel DNs were slightly higher. Illumination conditions were extremely good during the campaign. PAN-sharpening lowered the image DNs of multispectral channels slightly.

PAN-channels and multispectral channels, except NIR, of ADS40 were saturated at the third brightest target of reflectance about 42%. On unsaturated regions the linearity of the sensor was good. The camera parameters used during the flights were not optimal for this kind of radiometric analysis.

### 3.2 Noise and radiometric resolution

Results of noise evaluations are presented in figures 3 and 5. The relative standard deviation was used as an indicator of radiometric resolution of the system. If the dynamics of the sensor is narrow and / or the target is overexposured, abovementioned relative standard deviation drops. Example of the former can be seen in figure 5 with the RC20 at 20% target and UltraCamD at 50% target, example of the latter can be seen in figure 3 with the target 70% on all sensors.

The noise of the digital imaging system should be relatively lighter with smaller DNs. Different filtering window sizes behaved similarly on all sensors: the smaller the window, the smaller the relative standard deviation. The question is, how well the filtering worked i.e. removed the target topography

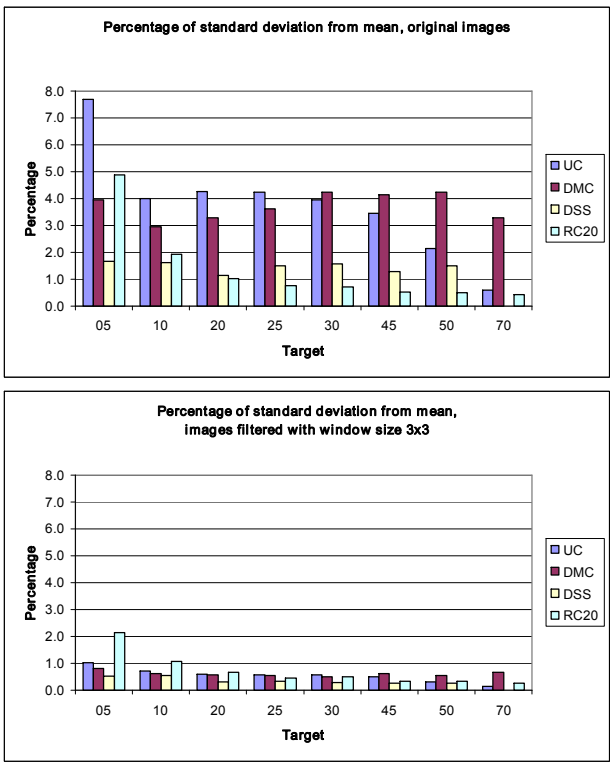


Figure 3. Original and 3-filtered relative standard deviations.

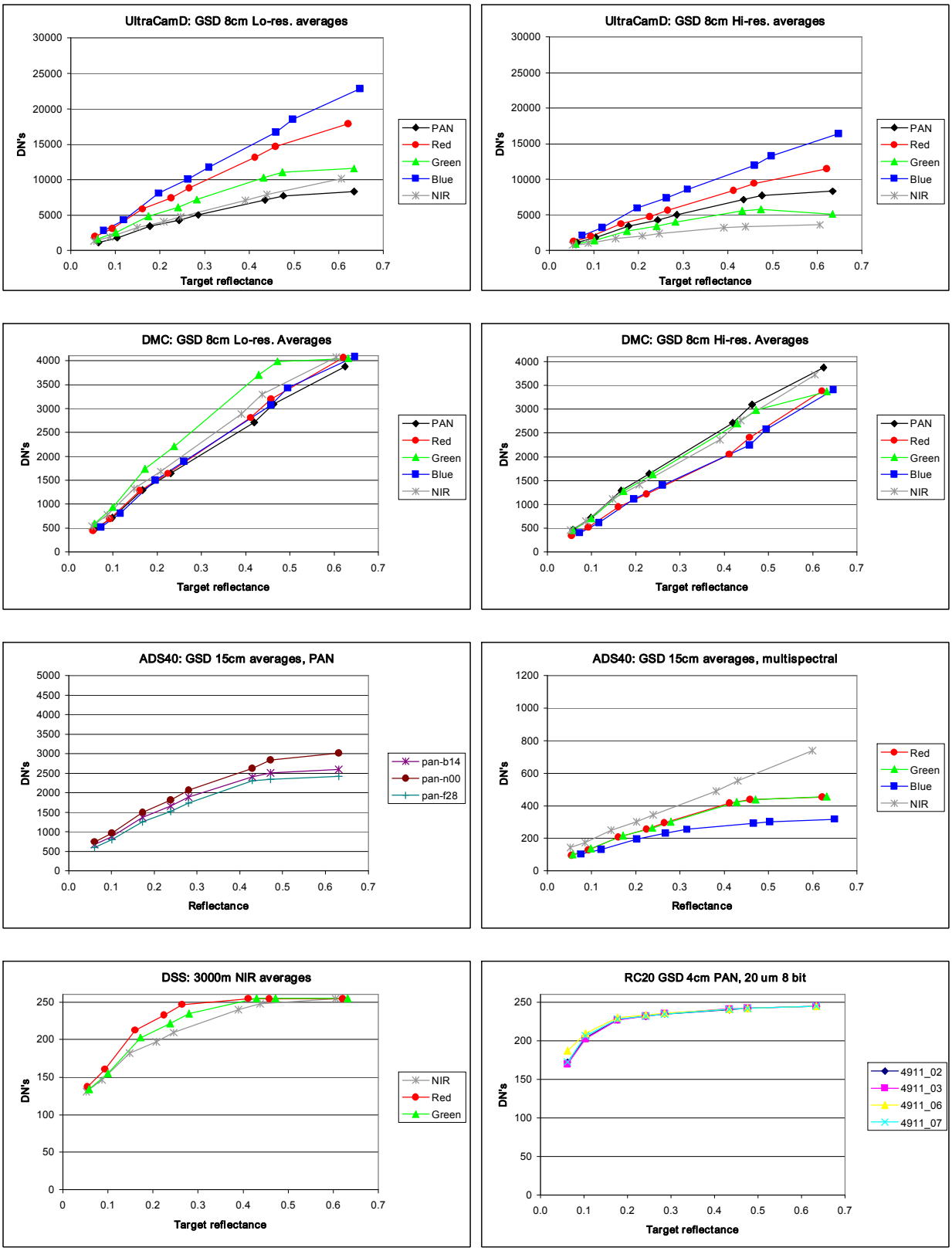


Figure 4. Grey scale measurements. From top to bottom: UltraCamD, DMC, ADS40, DSS and RC20. Notice the different DN-scale on Y-axis.

and revealed the actual system noise.

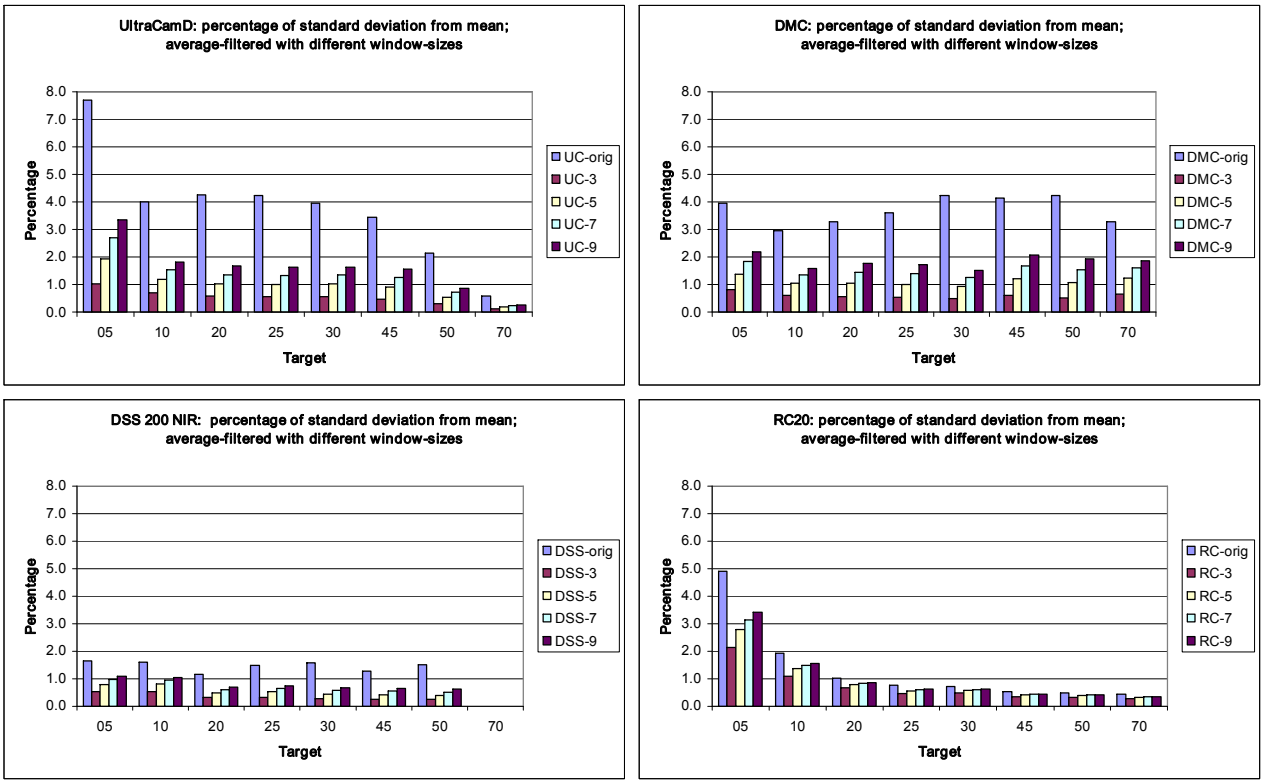


Figure 5. Noise evaluations of different sensors. Following targets are overexposured: UltraCamD 50, 70; DMC 70; DSS 70; RC20 25, 30, 45, 50 and 70.

Because of different weather conditions, sensor system and post-processing parameters, the results between different sensors are not completely comparable. The DSS-results are only from one multispectral image and its NIR-channel, whereas PAN-images were used for other sensors. DSS- and RC20 images were in 8bit-format, whereas UltraCamD and DMC images were in 16bit-format.

The noise analysis confirms the impression received from visual inspection of the images: digital sensors provide superior radiometric resolution and quality compared to traditional analog films.

## 4. CONCLUSIONS

Results of linearity, dynamic range, and radiometric resolution evaluation of data sets from digital large-format photogrammetric sensors Intergraph DMC, Leica ADS40 and Vexcel UltraCamD and from medium-format sensor Emerge DSS were presented in this article. Evaluation was performed using the calibrated 8-step gray scale of the FGI. The grey scale appears to be efficient tool for evaluating radiometric parameters of the sensors. In the future, one darker and one brighter target might be useful for covering wider dynamic range.

Results showed that depending on the data set, the saturation started at ground reflectance value of 27% to 66%. Because various data sets were collected in different conditions and the users of the systems had different experience levels, the comparison of the systems through the data sets is not possible. However, the results showed that in ideal conditions and with appropriate parameters a uniform radiometric response could be obtained in the entire tested reflectance range of 6% to 66%.

Many sensor settings during the image collection can affect the radiometric performance; important ones are the exposure time, aperture, automatic vs. fixed exposure and aperture, and possible compression of the data. During the post processing non-linear tonal adjustments destroy the linearity of the radiometric information but on the other hand, provides attractive data sets for the visual evaluation tasks. The purpose of images must be known before the flight in order to select optimal sensor settings and post processing parameters.

Our future studies will concern more detailed radiometric performance analysis and absolute radiometric calibration, by utilizing BRDF field measurements and atmospheric corrections.

In the analysis of sensor linearity in field conditions, one must take into account the effects of illumination changes, target BRDF-properties and atmospheric conditions.

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